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On Technical Performance Estimation of a Gas Turbine with Variable Power Turbine Vanes

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Abstract

The results of a special methodology design for technical performance of a gas turbine with variable nozzles are presented in the paper. The data are provide for the industrial implementation experience and special heat engineering tests on appropriate machines. The methodology was designed with the use of approximated manufacturer characteristics where dependencies from initial conditions and GT load were adopted.

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Keywords: Gas Turbines; Technical performance estimation; Opeartion of Gas Turbines; Variable geometry in turbomachinery

1. Introduction

Technical performance estimation is one of the most important task during Gas Compressor machine with Gas Turbine drive. Based on so called coefficients of technical performance (CTP) by power and efficiency key solutions to be made regarding operational mode of the machine and the whole plant. It also can be used for pipeline loading, maintenance forecast and appropriate financial planning [1-3].

There are more than 90 machines in Gas Transportation company fleet, that were made with variable nozzles of Power Turbine. These machines are GTK-25I (MS5002B) and GTK-10I (MS3002B). For such machines technical performance estimation brings some difficulties, since the classical method that implies comparison to nominal mode has one more uncertainty: variable nozzle position. Due to that fact currently CTP online estimation for these machines has some uncertainties and the operation personnel has no instruments to solve it. Currently there are

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methods for CTP estimation of such machines but it needs proper additional instrumentation and significant labor consumption, so it can be done only during special test, but not online [4, 5].

Meanwhile the problem becomes more important since the age of these machines is close to its limit and failure risk grows rapidly.

Nomenclature

N	power
k	coefficient
T	temperature
P	pressure
n	rotation speed;total number of measured points
η	efficiency
ξ	losses

Subscripts

2	parameters at power turbine
a	ambient condition
in	inlet
out	outlet
nom	nominal value
e	effective
T	turbine
C	compressor

Superscript

cha	characteristic
i	value at ideal engine condition
r	value at real engine condition

Abbreviations

CTP	Coefficient of technical performance
GT	Gas Turbine
GTK	Gas Turbo Compressor (Russian acronym)
PT	Power Turbine

2. Method description

The method is based on comparison of real engine power that is produced at real engine on site and one that should be provided by brand new engine but at the same atmospheric conditions. So the real power value includes losses due to weariness, higher tip clearances, dust on blades and so on. The proportion of this two values is called the coefficient of technical performance by power. Similar CTP can be calculated by efficiency comparison [4].

First of all one remark should be added. The method is very much rely on engine characteristics provided by producer for brand new engine. There are several reasons why this data should be properly processed and presented values may not be reached on real Gas Compressor Plant. First, the inlet and outlet conditions of GTU are not in the scope of turbine producer, so the engine characteristic can be provided for ISO conditions and should be adopted for different filtration and exhaust systems pressure losses. Second, the engine can be modified during its operation in order to have better emissions, higher efficiency or reliability.

Therefore the most important result of producer characteristic approximation is the behavior of the engine at part loads and varying atmospheric conditions, since that behavior can be realized in many ways and could not be guessed by any physical means. Once the position of variable nozzles, maximum available power and efficiency areknown, the CTP calculation can be performed. But only comparative analysis can be made. For example, before axial compressor washing the CTP was 0,8 and after washing - 0,83. So the relative gain is 3,75%. But this does not mean that the engine performance could be improved by 25% more, since the real maximum performance due to site limitations remains unknown.

Real power value is gained by natural gas compressor which is for this case the only power consumer for Power Turbine. The value of ideal power is gained according to approximated producer characteristics. In current paper the dependencies for power and efficiency were used for the following types of machines: PGT-10, M5352(B), M5322R(B), M5352R(C) and can be presented as:

$$N_e^{cha} = f\left(n_{PT}, T_{T2}, T_C\right) \tag{1}$$

$$\eta_e^{cha} = f\left(n_{PT}, N_e^{cha}, T_C\right) \tag{2}$$

where N_e^{cha} - effective power of GTU according to producer's characteristic; η_e^{cha} – effective GT efficiency from characteristic; n_{PT}– Power Turbine rotation speed; T_{T2} – exhaust gas temperature; T_C – compressor inlet air temperature.

On Figure 1 the characteristic is presented for M5352R(C) machine.

The effective GT power at its best condition can be described as following:

$$N_e^{cha} = a + b\cdot n + \frac{c}{T_{T2}} + d\cdot n^2 + \frac{e}{T_{T2}^2} + \frac{f\cdot n}{T_{T2}} + g\cdot n^3 + \frac{h}{T_{T2}^3} + \frac{i\cdot n}{T_{T2}^2} + \frac{j\cdot n^2}{T_{T2}}, \tag{3}$$

where n – Power Turbine shaft speed rpm; T_{T2} – exhaust gases temperature, K; $a, b, c, d, e, f, g, h, i, j$ – variable coefficients, defined for every GT type and axial compressor inlet temperature. These coefficients can be defined as:

$$\begin{aligned} a &= T_C\cdot k_{1a} + k_{2a}, \\ b &= T_C\cdot k_{1b} + k_{2b}, \\ c &= T_C\cdot k_{1c} + k_{2c}, \\ &\ldots \\ j &= T_C\cdot k_{1j} + k_{2j}, \end{aligned} \tag{4}$$

where T_C – axial compressor inlet temperature, K; k_i – constant coefficients for GT type and prescribed axial compressor inlet temperature range.

Effective power at ideal condition above is calculated regardless inlet duct and exhaust system pressure losses, so the inlet pressure is considered as 1,0132 bar. Therefore additional correction is added as following:

$$N_e^i = N_e^{cha}\cdot k_{N_e^{cha}}^{\xi_{in}}\cdot k_{N_e^{cha}}^{\xi_{out}}\cdot k_{N_e^{cha}}^{P_a}, \tag{5}$$

where N_e^{cha} – power value, gained from producers characteristics; $k^{\xi in}$, $k^{\xi out}$, k^{Pa} – correction coefficients for inlet and exhaust losses and also for atmospheric pressure deviation.

The correction coefficients for effective power for the following types M5352(B), M5322R(B) и M5352R(C) are:

$$k_{N_e^{cha}}^{\xi_{in}} = 1 - 0.000167\cdot\xi_{in}, \quad k_{N_e^{cha}}^{\xi_{out}} = 1 - 0{,}000069\cdot\xi_{out}. \tag{6}$$

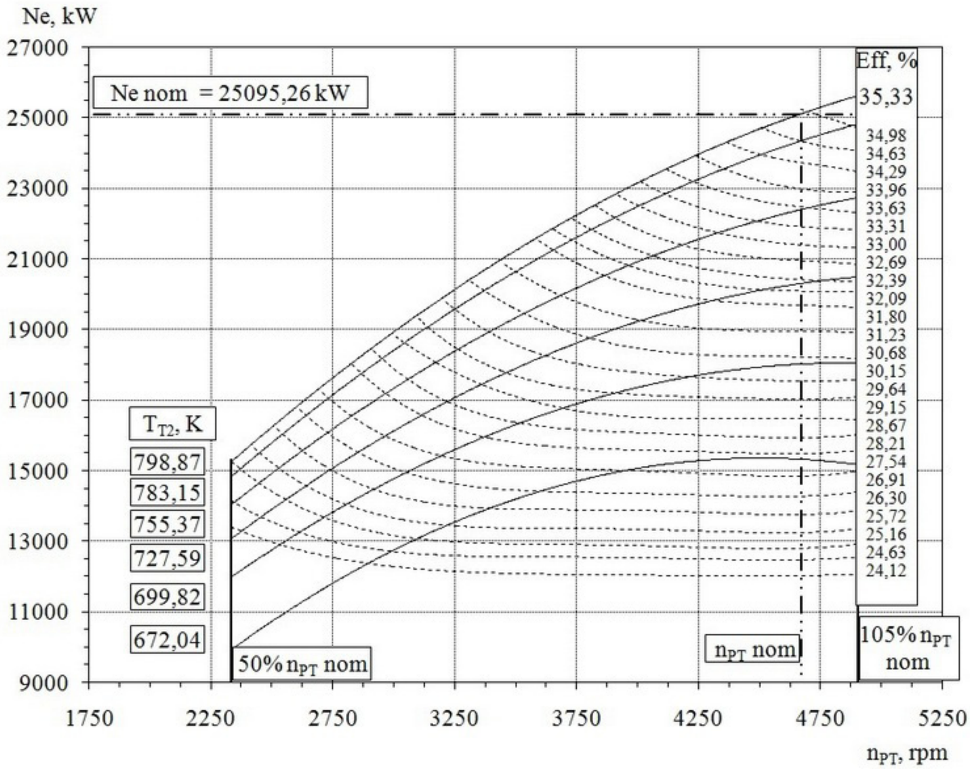

Fig.1.Machine operation characteristic for M5352R(C) type at ambient condition15 ^{0}C.

The same for PGT-10:

$$k_{N_e^{cha}}^{\xi in} = 1,000132 - 0,000171 \cdot \xi_{in}, \quad k_{N_e^{cha}}^{\xi out} = 1,000075 - 0,00007 \cdot \xi_{out}, \tag{7}$$

wherevξ_{in}, ξ_{out} – pressure losses in the inlet and outlet ducts correspondingly in mm of water.

The correction coefficients for atmospheric pressure:

$$k_{N_e^{cha}}^{P_a} = \frac{P_a}{760}, \tag{8}$$

where P_a – real atmospheric pressure in mm Hg.

The efficiency for engine at best condition according to approximated characteristics can be defined as:

$$\begin{gathered}\eta_e^{cha} = a + b \cdot \ln(n) + c \cdot \ln(N_e^{cha}) + d \cdot (\ln(n))^2 + e \cdot (\ln(N_e^{cha}))^2 + f \cdot \ln(n) \cdot \ln(N_e^{cha}) + \\ + g \cdot (\ln(n))^3 + h \cdot (\ln(N_e^{cha}))^3 + i \cdot \ln(n) \cdot (\ln(N_e^{cha}))^2 + j \cdot (\ln(n))^2 \cdot \ln(N_e^{cha}),\end{gathered} \tag{9}$$

where n – Power Turbine speed, rpm; N_e^{cha} – effective power at best condition according to producers characteristics, kW; *a, b, c, d, e, f, g, h, i, j* – variable coefficients, defined for every GT type and axial compressor inlet temperature.

For given current operational parameters the efficiency at best condition can be defined. So the coefficient of technical performance by efficiency can be defined as:

$$k_{TP} = \frac{N_e^r}{N_e^i}. \qquad (10)$$

In order to have reliable data regarding technical performance the series of calculation is needed at the wide range of power and atmospheric conditions. Then the averaged CTP can be calculated:

$$K_{TP}^{'} = \frac{\sum_{i=1}^{n} k_{TPi}}{n}, \qquad (11)$$

where i – the sequence number of measured point $1 \le i \le n$; n – total number of measured points; k_{TPi} – CTP for i-mode.

3. Experimental process and model verification

Since the real tests were made on site the real operation conditions of the Compressor plant were respected as well as some limitations regarding wide instrumentation requirements [6-7]. The data was registered and recorded to the hard disk and then analyzed. Degradation curves were built up and controlled for each Turbine Unit on every Pumping station. The character and qualitative behavior of data collected lays in good agreement with [8]. Also very important notes and references regarding this problem are presented in [9].

It is very important to have stable mode to be recorded. If the parameters are still changing they should not be processed otherwise this will bring significant error later on. The parameters are considered to be stable if the deviation of parameters including variable nozzles position is less than 1% in one hour. Also the deviation of inlet and outlet temperatures of natural gas centrifugal compressor should be less than 0,1 degree in 10 minutes.

The measurements were made for the control algorithm that does not include control of inlet variable guide vanes of axial compressor, so it remains at the same position. The method verification was made based on operational parameters registered for several Gas Turbines of GTK-25I type, that are working at different compressor plants at Gas Transportation company. As an example at figures 2 and 3 comparative characteristics are presented for real power value and one for GT best conditions at different operational modes.

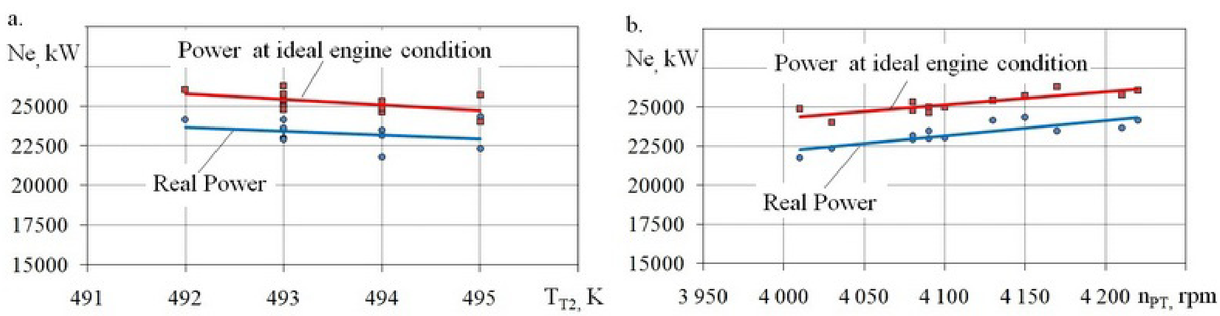

Fig.2.Real measured power (blue line) and power at ideal engine condition (red line) at different operational modes for GTK-25I, on Station 1: as function of exhaust gases temperature (a); as function of Power Turbine rotation speed (b).

4. Conclusion

According to special tests of real engine operation on site for GTK-25IR the methodology presented showed its ability for coefficient of technical performance estimation for Gas Turbines with variable nozzles of Power Turbine. Key factor of this estimation is the nozzle behavior as a function of atmospheric conditions and load. In the current work the engine producer characteristics gave reasonably good precision.

The methodology is realized in in-house code distributed for on-site operational needs, that can be used for reduction of failure risks and maintenance forecast and preparations.

Presented method can be applied for similar types of Gas Turbines with variable nozzles. In any case proper verification is needed by means of manufacturer documentation and proper instrumented test on site.

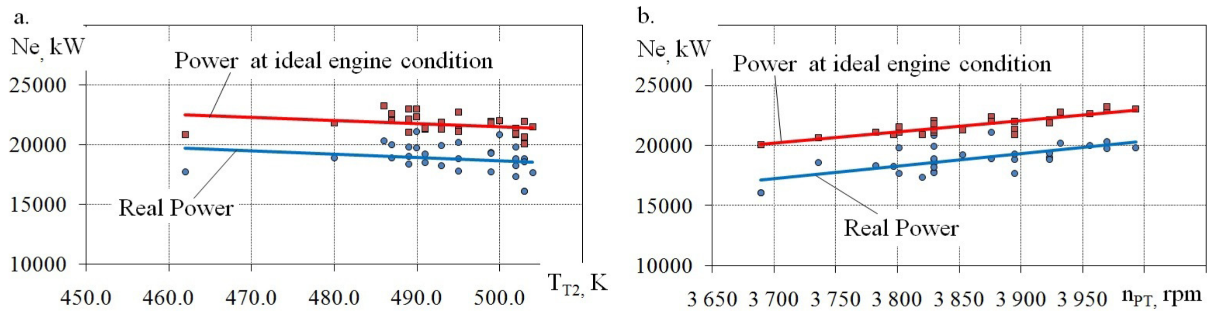

Fig. 3.Real measured power (blue line) and power at ideal engine condition (red line) at different operational modes for GTK-25I, on Station 2: as function of exhaust gases temperature (a); as function of Power Turbine rotation speed (b).

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